SUBSIDENCE IN MARITIME AIR OVER THE COLUMBIA AND SNAKE RIVER BASINS

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[Weather Bureau, Portland, Oreg., October 1935]

The Columbia and Snake River Basins are surrounded by the Rocky Mountains to the northeast, east, and southeast; a high plateau to the south; and the Cascade Range to the west. In addition to this almost continuous rim that surrounds the combined basins, there is the ridge of the Blue Mountains between them. The most notable and most effective outlet for this great area is the Columbia River Gorge.

The period covered in the present study extended from January 19 to February 10, 1935; and the problem investigated is that of subsidence in the maritime air associated with low stratus clouds and fog. This type of stagnation is not uncommon in the Columbia River Basin east of the Cascade Range, but it is less common for the effects of this stagnation to reach over into the Snake River Basin, and to be persistent for such a long period. These weather effects are easily seen on the short-period airway weather maps prepared at Portland, Oreg. This study is based on these maps in conjunction with the large Map A; airplane soundings at Seattle, Spokane, and Billings; "weather logs" from pilots of the air lines; and

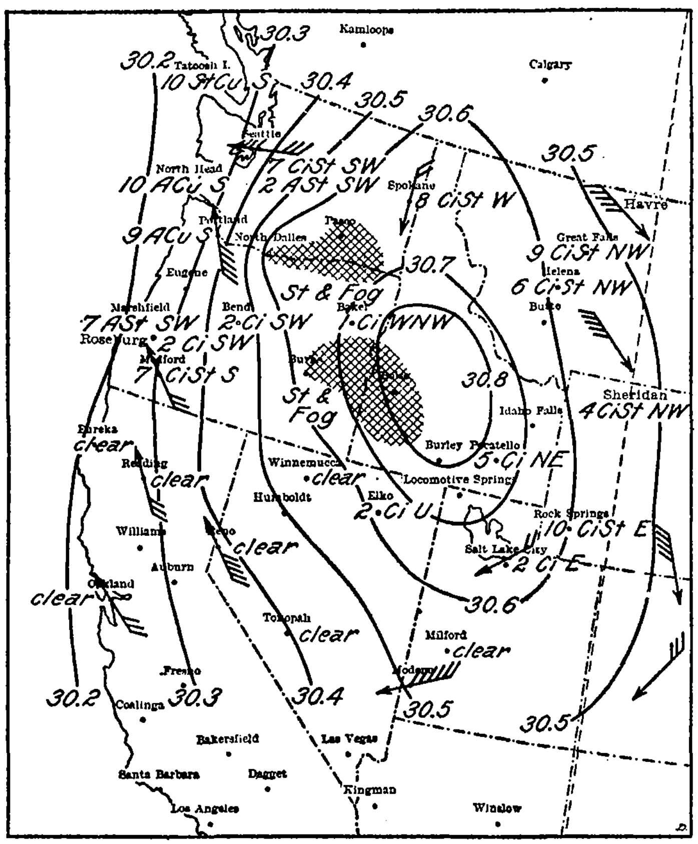

FIGURE 1.—February 2, 1935, 1 p. m. Mean sea-level isobars, winds at 8,000 feet, and high cloud movements.

associated data. The air-mass names are those used by Willett (**1**), and the references to subsidence are intended to follow the lines suggested by Namias (**2**).

The entire far western part of the United States received precipitation in the few days prior to January 19. By this time, the last of a series of disturbances had moved into Utah from the Oregon coast. This particular direction of movement is favorable to development of stagnation in the drainage areas of the Columbia and Snake Rivers. The air mass that followed was characteristically polar Pacific (*Pp*), with showers over Washington and parts of Oregon for several days. No airplane observations were available in this air mass to further identify it. Surface radiation and air drainage in the Columbia River Basin produced the first patches of fog and low clouds on the east slope of the Cascade Range on the morning of January 24. These fog patches increased

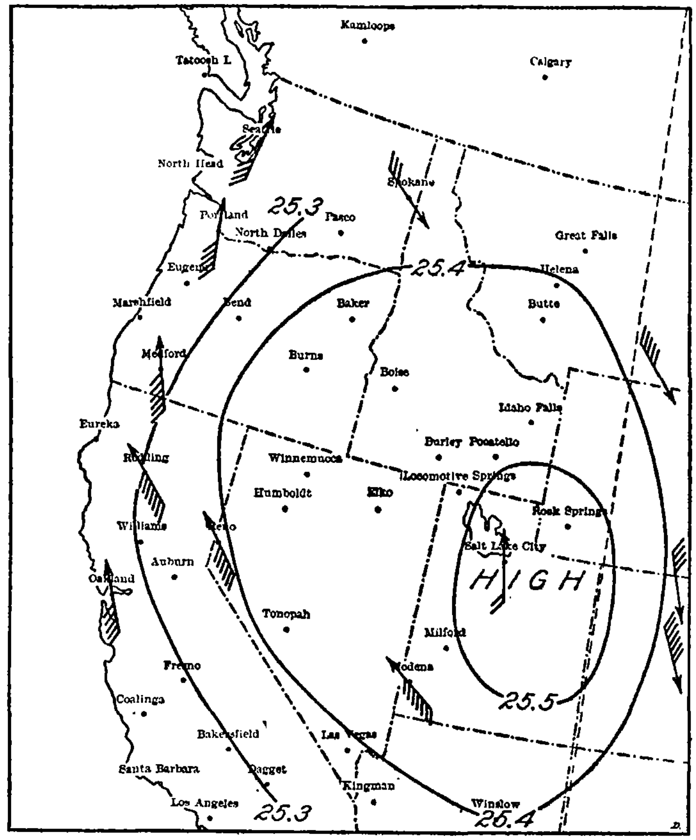

FIGURE 2.—February 2, 1935, 1 p. m. Isobars at the 5,000-foot level, and winds at 14,000 feet.

in size and duration on the succeeding mornings, with light fogs also forming in the Boise area on January 25 and 26, and with dense fog reported from Boise on the 27th. By January 28, the air mass over the Columbia and Snake River Basins had become sufficiently stable for dense valley fogs to continue throughout the day. Mixed local smoke and fog formed at Salt Lake City each evening, and became an increasing hazard to aviation in the days that followed.

It is difficult, without airplane soundings from Boise or Salt Lake City, to show subsidence in the air mass with its dome apparently located over this area. This location for the dome top is based on the relation between the sea-level pressures, with high pressure centered near Boise, and the 5,000-foot pressures with a center east of Salt Lake City. Upper air winds at 8,000 feet indicate the center just north of Salt Lake City, and the winds at 14,000 feet indicate the center between Salt Lake City and Rock Springs (figs. 1 and 2).

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Since this study is necessarily based on data available at Portland, Oreg., an attempt will be made to prove subsidence in this air mass, with the information available. On January 23, a low inversion was evident over the Pendleton-Pasco area. This was apparently the beginning of subsidence. Radiation from the surface, and air drainage into this area, had already begun. From January 24 to 29, this cold surface layer, and the warm layer above, both became deeper and deeper, as evidenced by temperature reports from air-line pilots (fig. 3). On January 29, this warm layer became apparent in the low levels of the Spokane sounding (fig. 4). The layer between 1.2 and 1.9 kilometer was both warmer and drier than on the previous day. The winds in this layer were light southeasterly, and were a part of a similar deepening layer of light southeasterly winds over Boise. The 9 a. m. balloon run for January 29 was the last available from Boise until 9 p. m. February 5, due to fog and low clouds. The winds at Spokane were moderate to fresh southwest to west except during periods such as mentioned above when air from subsidence layers flowed out in low levels over the Spokane area. These warm currents of air were most pronounced when cyclonic activity across Canada was at a minimum. The moderately steep lapse rates in intermediate and high levels over Spokane occurred in air that was traveling from the Pacific Ocean toward disturbances which were moving across Canada.

Closely associated with the above subsidence layer indicated at Spokane was the steady increase of easterly winds in the Columbia River Gorge, beginning with a total movement of 181 miles on January 24, and increasing steadily to a maximum total movement of 940 miles

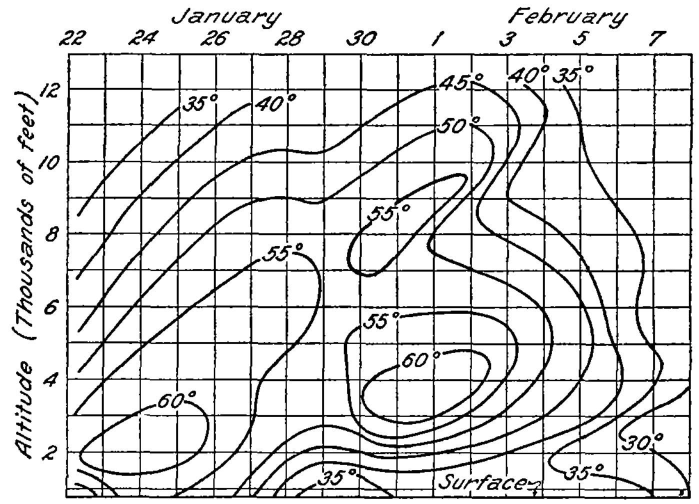

FIGURE 3.—Free-air temperatures (F.) over the Pendleton-Pasco area, January 23–February 8, 1935.

of easterly winds on January 29. This represents an average hourly velocity of 39.2 miles per hour for the Crown Point station (6) on the latter date. Strong easterly winds continued uninterrupted at this station

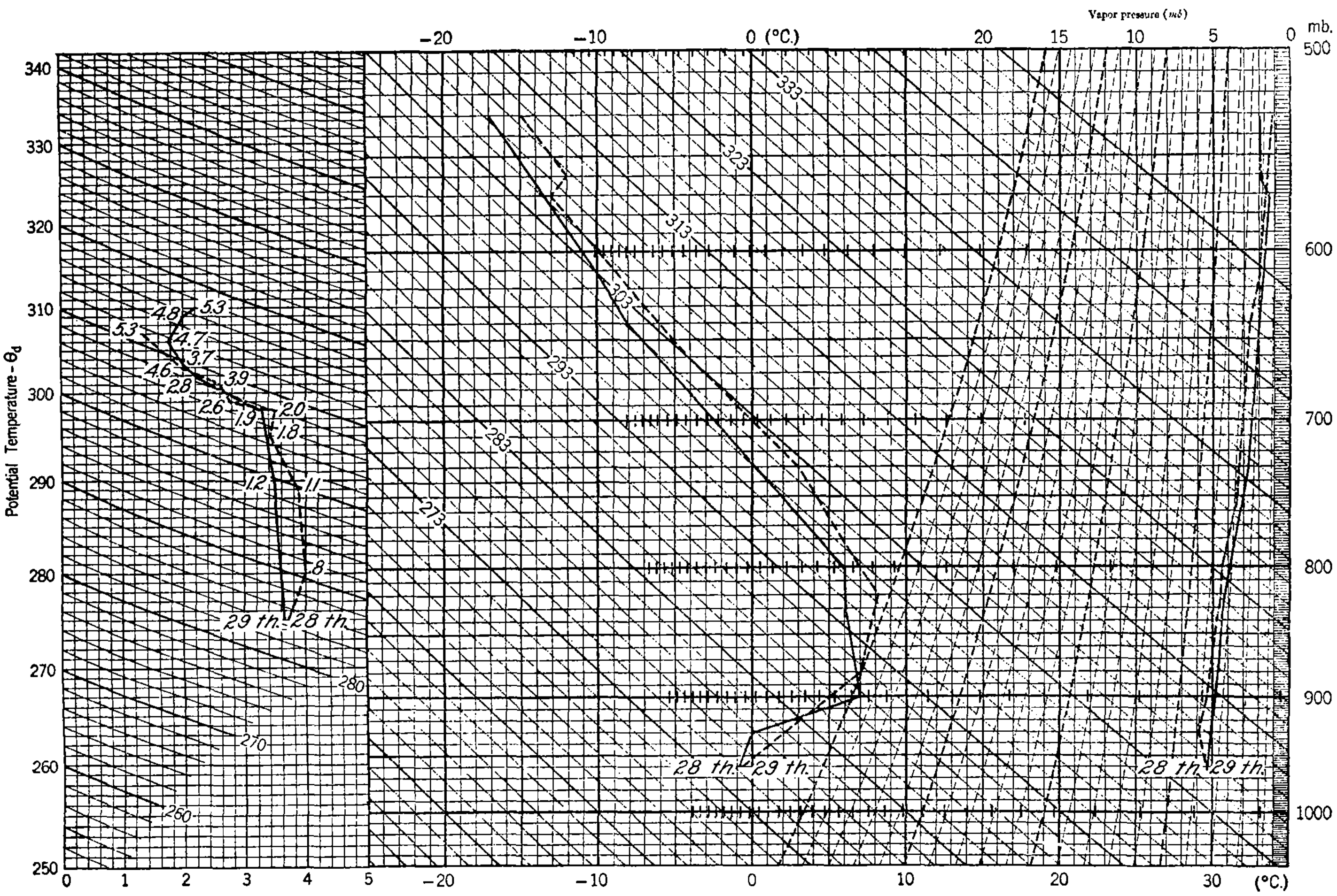

FIGURE 4.—Adiabatic charts for soundings at Spokane, Wash., with equivalent-potential-temperature diagrams, January 28 and 29, 1935. Shows stability of the air, and the beginning of subsidence.

until February 10. Total wind movement from the east was 10,673 miles for 18 days, or an average of 24.7 miles per hour. The average temperature in these easterly winds at Crown Point was approximately 40° F. (4.5° C.). This steady, strong flow of moderately warm easterly winds, for such a long period, was surely associated with subsidence in the air mass to the eastward.

On January 30, easterly winds set in at Government Camp and continued easterly until February 11, with light to moderate velocities. Government Camp is located on the south slope of Mount Hood in the Cascade Range, approximately 60 miles east-southeast of Portland, Oreg.

At Spokane on January 30, the southeast winds in the low levels had been entirely displaced by southwest winds with attendant lower temperatures. However, on January 31, the southeast winds from the subsiding air mass were again present, with higher temperatures and lower moisture content than on the previous days.

Evident at the top of the Spokane sounding for January 29, was an occluded front. This front was the only one of any consequence in this area of frontolysis to the south of Spokane. At Boise, pressure waves began with a maximum just before midnight a. m. January 29, and reached successive maxima at 4-hourly intervals, with the final maximum at 11 a. m. The pressure decreased 0.05 inch between each of the maxima. The winds were variable, with velocities from 3 to 5 miles per hour, but with no apparent relation to the pressure waves. Temperature changes were insignificant. Surface weather was dense fog until 7:30 a. m., then ground fog clearing slowly. Dense fog formed again in the evening under conditions identical with those of the previous evening, indicating no change in air mass at the surface or in the lower levels. The structure at intermediate levels appears to have been changed, with the beginning of two inversion layers instead of the one previously indicated by temperatures from air line pilots.

Evidence of the dome structure is found in the "weather logs" turned in by pilots of the air lines at the end of each trip. On February 3, the eastbound pilot reported the top of the fog layers at 3,000 feet (0.9 kilometer), in both the Columbia and Snake River Valleys. The next layer above the fog had a ceiling of 9,000 feet (2.7 kilometers) over Boise, and sloped down to a ceiling of 6,000 feet (1.8 kilometers) over Cascade Locks in the Columbia River Gorge. This upper layer was 1,000 to 2,000 feet thick, and the pilot reported an entire lack of turbulence in the clear layers. The temperatures reported by air line pilots over the Pendleton area indicate two inversions, one at approximately 5,000 feet (1.5 kilometers), and another at 11,000 feet (3.4 kilometers). In each case the cloud layers formed below the subsidence inversions. The upper inversion is evident in the Spokane sounding for February 3 (fig. 5).

A cloud layer did not form beneath the inversion at Spokane. The cloud layer over the Pendleton-Boise area indicates a sharper inversion, higher humidity in the cloud level, and a drop in humidity through the inversion just above the clouds. This inversion layer

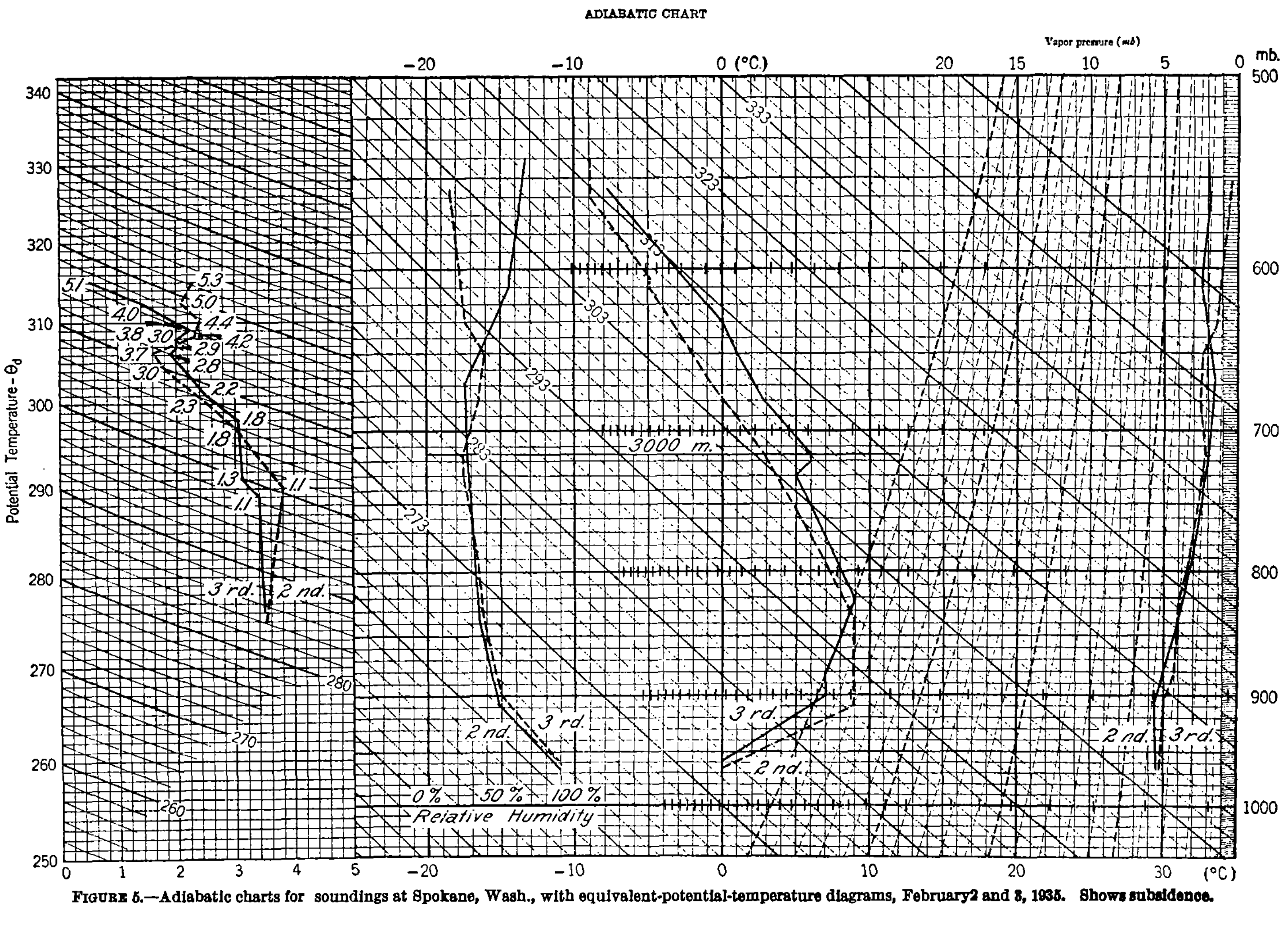

FIGURE 5.—Adiabatic charts for soundings at Spokane, Wash., with equivalent-potential-temperature diagrams, February 2 and 3, 1935. Shows subsidence.

is quite similar to one over Cleveland, Ohio, on October 7, 1932, described by Namias (2) as follows:

From the sharp drop in humidity through the upper inversion it is clear that the *Tp* air is certainly not actively ascending the frontal surface, and it is probable that the colder air below the inversion is retreating at a faster rate than the warm *Tp* air is advancing. This velocity distribution characterizes the discontinuity surface as a surface of subsidence, despite the fact that the discontinuity separates two different masses of air.

The day and night continuation of fog and low stratus is a good indication of subsidence. Namias (2) states that—

Subsidence inversions are generally of greater intensity than ordinary radiation inversions, and since some subsiding motion is usually continuing, it is manifest that these low subsidence inversions are not completely wiped out during the day. This is in contrast to those due entirely to radiation.

The above is substantiated by the unchanging moderate to strong easterly winds in the Columbia River Gorge, and by the easterly winds passing over the Cascade Range from warm subsidence layers. Very light changeable winds were reported in the fog and stratus areas beneath the inversion. Temperatures from air line pilots indicate the continuance of a decided inversion throughout the daytime hours (fig. 3).

The specific humidities on January 31, at the stations of Boise, Baker, Bend, Burns, Lakeview, Winnemucca, Elko, Salt Lake City, Pocatello, and Helena were all between 3.2 and 4.1 grams per kilogram. Seven of the 10 stations agreed within 0.4 grams per kilogram. This close agreement of the specific humidities was notable from January 29 to February 5, indicating stagnation and subsidence in one large air mass. Specific humidities in the Columbia River Basin, and westward to Portland, ranged from 4.5 to 4.8 grams per kilogram. This higher moisture content was no doubt due in part to evaporation from the warm, moist soil, as suggested by Counts (3) in a similar situation. The specific humidity at La Grande was 4.2, at Pasco 4.5, at Hood River 4.7, and at Portland 4.8 grams per kilogram, indicating a continual increase in moisture content as the air flowed from La Grande to Portland. Easterly winds prevailed in the Columbia River Gorge, and southeasterly winds prevailed in the La Grande area throughout the entire period. The winds through the Pasco area and westward to the gorge were very light. No doubt the specific humidity at Portland was lowered by mixing with a southeast air flow coming directly over the Cascade Range from an intermediate layer of the air mass.

The subsidence was very much slower than would be expected in other areas, where spreading could take place more easily and rapidly. Here the subsidence from the lower layers had to depend on the slow flow through mountain passes, and across high plateaus. It will be noted that subsidence layers, when indicated in airplane soundings, were usually at low levels, because the airplane stations were located around the periphery of the dome. High pressure was usually centered over the Snake River Basin in Southern Idaho.

Further evidence of subsidence in this air mass is found in the general weather sequence for the northwestern section of the United States including Idaho, Montana, Wyoming, Colorado, Utah, Nevada, Oregon, and eastern Washington. The above includes an area with a radius of approximately 500 miles from the center of the subsiding air mass. On January 28, at 5 a. m., generally cloudy weather prevailed over this area. On the following day, clear skies covered most of the area, except for the fog and stratus areas in the Columbia and Snake River Basins. This clearing would be expected in a subsiding air mass with no appreciable change in pressure distribution at the surface. By January 30, clear skies prevailed at nearly every station in the above area, and in the following 5 days clear weather also spread slowly eastward across the United States. The clear weather was no doubt a result of the combined subsidence and frontolysis.

Closely associated with the above, is the absence of precipitation over the same area. Twenty-four of the twenty-six regular Weather Bureau stations had no precipitation during the period from January 25 to February 5. The remaining two stations, on the western and northern extremities of the area, had a total of 0.09 inch. This precipitation occurred before the stations were affected by subsidence in the air mass under consideration.

At Spokane, it is interesting to note the fog layers which formed beneath the lower inversion on the mornings of February 4 and 5. These were the only occasions on which the deeper fog layer in the Columbia Basin spread that far to the northeast, and this was due to increased diathermancy of the air mass above.

On February 5, *Npp* air moved in over the Columbia River Basin above an elevation of 1.7 kilometers, as evidenced by airplane soundings at Spokane (fig. 6). This same mass of *Npp* air was evident in the Seattle sounding on the previous day. During the day, February 5, the fog layer at Pasco began to show signs of weakening, probably because of a small amount of mechanical mixing with the new layer above. Near midnight of the 5th, the cloud top at Pasco was 3,300 feet (1 kilometer) above sea level, and it was 1,800 feet (0.5 kilometer) thick, with a ceiling of approximate y 1,100 feet (0.4 kilometer). The surface fog had dissipated.

February 6 brought a noticeable weakening of the low overcast, no doubt due to mixing with the new air mass above. In the meantime a disturbance had moved in over northern Nevada, on the south rim of the area being studied. The pressure at Winnemucca was 29.8 inches on the a. m. map. This storm produced a north-south pressure gradient. The first effect was to help draw out the stagnant air from the Columbia and Snake River Basins. This favored the importation of the *Npp* air previously mentioned over Washington. In the progress of the storm, clouds were formed over the Snake River Basin, thus reducing the diathermancy of the air to such an extent that the return radiation from above was too great to permit further continuance of the fog below.

La Grande, and Baker, Oreg., enjoyed persistently good flying weather during the southeast-northwest pressure gradient previous to the evening of February 5. Topography of the area seems to be the reason for the good weather. The Snake River Basin is separated from the Columbia River Basin by the ridge of the Blue Mountains, except for the narrow, deep gorge of the Snake River, which in itself is not sufficient to carry off any material volume of air flow.

This makes it necessary for the surface air flow to seek other channels, and it spills over into the valley surrounding La Grande. From there it finds an exit through the valley of the Grande Ronde River into the lower reaches of the Snake River, and finally flows out into the Columbia River Basin. The major subsidence taking place over the Snake River Basin had to find a way out, and La Grande benefited. Surface temperatures at La Grande were higher than those in the Snake River Valley, due to turbulent mixing with the warmer air above. Pilot logs with such reports as "Very rough vicinity La Grande, smooth otherwise", were indicative of conditions at this time. It has been noted that these southeast surface winds at La Grande are sometimes a better indication of pressure gradient than are the sea-level isobars for this area.

Another noticeable effect of subsidence in the air mass with its main body over the Snake River Basin is the fair weather produced in the coastal valleys. From 1 p. m. January 24 until 9 p. m. February 10, Portland, Oreg., had only 0.02 inch precipitation. Average temperature at Portland from January 22 to February 11, inclusive, was 8.5° F. above normal. The cumulative departure was plus 178° F. Associated with this fair weather was the average pressure gradient of 0.31 inches directed from Boise toward Portland during the period. The normal pressure gradient from Boise to Portland for the 3 winter months is 0.06 inch.

The above findings lend support to the theory, advanced by B. S. Pague (4), that dynamic heating plays an important part in the warm climate of this area. These findings also agree with the following statement by Byers (5) in reference to weather of the Pacific coast: "Since nearly all the air which moves out over the ocean from the interior is a return current of maritime air and rarely continental, this kind of mountain modification is important in a study of coastal weather." The history of the air mass, the temperatures in the inversion layers, and the specific humidities, all indicate a previous maritime history as suggested by Byers in the above statement.

In summarizing this study it appears that the fairly common winter high-pressure area, centered over southern Idaho, is intensified by cooling in the lower levels of a large mass of stagnant maritime air. This cooling in the low levels is productive of low stratus clouds and fog in the Columbia River Basin, and later in the Snake River Basin, if the stagnation continues. Foehn-heated currents of air from intermediate subsidence inversions, flowing westward over the Cascade Range into the coastal valleys, play an important part in the warm climate of the Pacific coast.

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ADIABATIC CHART

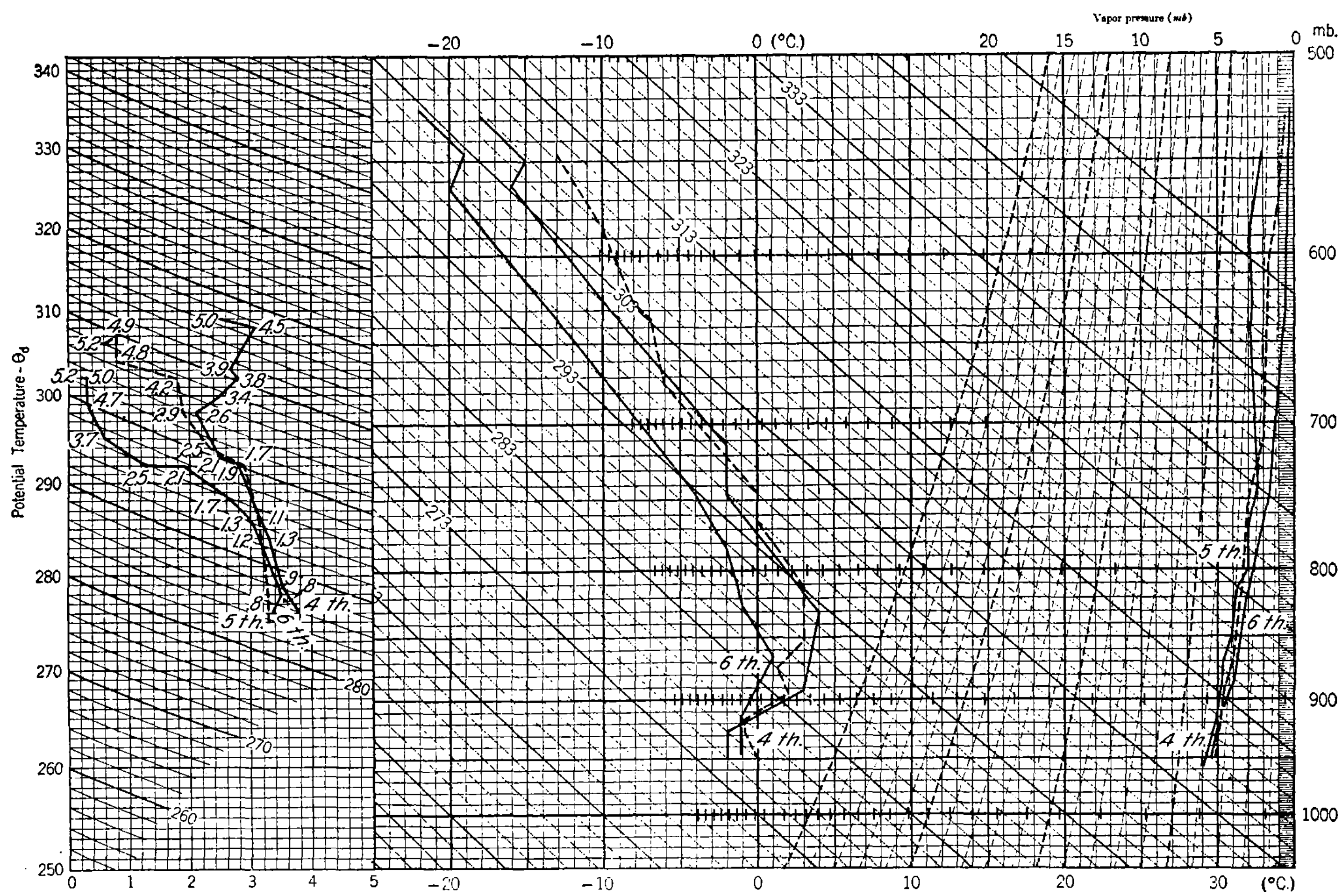

FIGURE 6.—Adiabatic charts for soundings at Spokane, Wash., with equivalent-potential-temperature diagrams, February 4, 5, and 6, 1935. Shows air-mass changes resulting in the breakdown of the system.